

**RTCA Special Committee 186, Working Group 3**

**ADS-B 1090 MOPS, Revision A**

**Meeting #3**

**1090 Radio Frequency Measurement Facility (RMF) Enhanced  
Reception Technique Implementation Software Description Revision**

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<b>SUMMARY</b>
<b>A new version of the 1090 RMF “Gold Standard” Enhanced Reception program has been developed that emulates reception limitations of a real-time application. The software description is contained in this working paper including details of the real-time design approach. This is a draft design that is subject of the approval of Working Group 3.</b>

## **1090 Radio Frequency Measurement Facility (RMF) Enhanced Reception Technique**

### **Background**

The 1090 Radio Frequency Measurement Facility (RMF) was developed as a means to analyze the 1090 RF environment. The RMF hardware consists of dual channel A/D converters that sample an incoming analog video signal at a 10 MHz rate and store the digitized data on high density digital tape recorders. The video signal is provided from a receiver external to the RMF. In Frankfurt, the receiver video signal was provided by the Link-Display Processing Unit (LDPU) for both the top and bottom antennas. RMF software was developed to analyze the recorded data to characterize the 1090 MHz RF environment, measure the extended squitter performance in high fruit rate environments, and evaluate the performance of the improved mode S processing techniques. The RMF data is processed off-line to detect extended squitter messages and other Mode S messages using the enhanced reception techniques defined in the MOPS appendix I. The details of the RMF software implementation are contained below.

### **Pulse Positions and Leading Edge Positions**

Of fundamental importance to the message decoding process is the location of pulses and their leading edges. With the RMF software implementation, a pulse consists of 4 or more successive samples above threshold. A valid pulse position is any sample that is above threshold and is followed by 3 other samples above threshold. Since the RMF samples at a 10 MHz rate, each sample is 100 nanoseconds apart. A minimum pulse is at least 300 nanoseconds in duration. The method described in appendix I is based on an 8 MHz sampling rate where a minimum pulse is 3 samples wide and therefore at least 250 nanoseconds in duration.

A leading edge is a valid pulse position that is 4.8 dB or more greater than its preceding sample and less than 4.8 dB lower than its succeeding sample.

### **Threshold**

The user may select either a fixed threshold at specified level in DBM or an adaptive threshold at a specified level (DBM) above noise. The adaptive threshold method uses a process to monitor and track the current noise level, the threshold will maintain a user defined level in DBM above the noise. The adaptive threshold was developed to provide a stable threshold when DC fluctuations in the signal level from the receiver are present.

### **Preamble Detection**

All pulses above the receiver threshold are detected. The preamble detection logic advances through the digitized data one sample at a time until a pulse position or lead edge is found. The pulse position or lead edge establishes a potential preamble reference position. For a preamble to be declared, there must be at least one lead edge or pulse position located within +/- one sample period of the nominal position of each of the three remaining preamble pulses.

The pulse sample timing tolerance is limited to either one sample plus or one sample minus but not both in the same preamble. If one pulse of a preamble set is present only in the - 1 clock position and another pulse is only present in the + 1 clock position then the preamble is cancelled.

Timing offset is limited to one direction during preamble detection. If there are 2 or more lead edges in either the +1 clock offset or -1 clock offset direction, then the reference position will be shifted in that direction. Otherwise the center position will be used. However, if the center position is selected and there are no lead edges declared in the center position a preamble is not declared.

It is required that there is at least 2 lead edges declared within the + or - 1 sample tolerance range of the four pulses with at least one of them in the reference position.

### **Preamble Validation**

It is required that there is a pulse position or lead edge declared within + or - one sample period of the start of the 1 chip or the start of the 0 chip for each of the first five data pulses of the message.

### **Reference Level Generation**

The reference level generation process begins by selecting amplitude samples from each of the preamble pulses that are considered appropriate candidates, namely only those that have leading edges declared in their reference positions.

The three amplitude samples after each valid lead edge position are entered into the reference level declaration algorithm (up to 12 samples are possible).

For each qualified sample amplitude, the amplitude is compared to all other qualified amplitude samples and the number that lies within plus or minus 2 dB is counted. If the highest count is unique, then the reference level is set to the amplitude of that sample. If there is a tie, it is resolved by removing all amplitudes from the tied set that are greater than 2 dB above the lowest amplitude in the tied set. The reference level is set to the average of all remaining samples.

### **Re-triggerable Preamble Detection**

The decoder will only re-trigger when a signal is already being processed if the determined reference level and the amplitude of all 5 data pulses of the new signal is at least 3 dB above the declared level of the existing signal. When in a re-trigger situation, the preamble validation step will require that there exists not only a pulse position or lead edge in the start of either the 1 chip or 0 chip, but that the amplitude resulting from the average of the three amplitude samples following the lead edge or pulse position found must exceed the amplitude of the reply in progress. This is required of all five pulses and all lead edges or pulse positions within + or - 1 clock of the start of both the one chip and the zero chip will be tested until a valid pulse amplitude is found or determined not to exist.

### **Enhanced Bit and Confidence Declaration**

There are currently three enhanced bit and confidence declaration techniques that have been developed for the RMF: the center sample method that follows the method defined in appendix I; a multiple sample method that is a variation of the center sample method; and the 5-5 multiple amplitude method that is a variation of the 4-4 multiple amplitude approach defined in appendix I.

### **Center Sample Method**

A high confidence one is declared when the center sample of the one chip is within + or – 3 dB of the preamble reference level and the center sample of the zero chip is not. A high confidence zero is declared when the center sample of the zero chip is within + or – 3 dB of the preamble reference level and the center sample of the one chip is not. If neither of the above conditions are met, the bit is declared low confidence and the bit value is awarded to the chip that has the highest amplitude. If the amplitudes are the same the bit value is set to zero.

### **Multiple Sample Method**

With a 10 MHz sample rate, each bit is sampled 10 times, 5 per chip. The multiple sample method utilizes all samples by counting the number of samples in each chip that are within + or – 3 dB of the preamble reference level. The bit value is determined by which chip has the highest count. A tie defaults to a bit value of zero. High confidence is assigned if the count differs by 3 or more, otherwise low confidence is assigned.

### **The 5-5 Multiple Amplitude Method**

Each of the 10 samples are quantized into four levels:

- 0: below threshold (-6 dB relative to the preamble)
- 1: above threshold but below the +/- dB preamble window
- 2: within the +/- 3 dB preamble window
- 3: above the +/- 3 dB preamble window

The 5-5 method forms two estimates of the bit data and confidence values, one using the odd samples (1-3-5-7-9) and the other using the even samples (2-4-6-8-10). The lookup value for the odd and even patterns are built from the five 2 bit quantized values. Therefore, there is a lookup table of size 1024 for both the odd and even patterns. The lookup tables provide one of the following values:

- H1: the pattern occurred 90% or more when the bit was a '1'
- M1: the pattern occurred 70% - 90% when the bit was a '1'
- L1: the pattern occurred 50% - 70% when the bit was a '1'
- L0: the pattern occurred 30% - 50% when the bit was a '1'
- M0: the pattern occurred 10% - 30% when the bit was a '1'
- H0: the pattern occurred 10% when the bit was a '1'

The odd and even values resulting from the lookup tables are used to index another table that provides the bit and confidence value. The odd / even pattern combining table is as follows:

### Odd and Even Sample Combination Table

	Odd (1,3,5,7,9)			Even (2,4,6,8,10)		
	H1	M1	L1	H0	M0	L0
H1	H1	H1	H1	L0	H1	H1
M1	H1	H1	L1	H0	L0	L1
L1	H1	L1	L1	H0	L0	L0
H0	L0	H0	H0	H0	H0	H0
M0	H1	L0	L0	H0	H0	L0
L0	H1	L1	L0	H0	L0	L0

### Enhanced Error Detection and Correction Techniques

The RMF enhanced reception implementation utilizes both the conservative and the Brute Force error detection and correction techniques. The method applied follows that recommended in appendix I.

#### Conservative Technique

This technique is attempted only if the span of all low confidence bits in a message is no more than 24 bits. There must also be a limit of 12 low confidence bits total. Error correction is successful when a conversion of some or all of the low confidence bits results in a zero error syndrome.

#### Brute Force Technique

The brute force technique is applied only when the conservative technique has failed. The brute force technique is applied only if there are 5 or less low confidence bits in the message, but the low confidence bits are not limited to a 24 bit span. Error correction is successful when a conversion of some or all of the low confidence bits results in a zero error syndrome.

### The RMF “Gold Standard”

The RMF 1090 environment analysis software was developed using the enhanced reception techniques to measure the Mode S fruit rate in high density fruit environments such as Los Angeles and Frankfurt Germany. When utilizing any of the methods described above, there are a high number of false triggers especially when using a low threshold. To counteract this effect, modifications to the technique and a number of filters were applied. The filter settings are selectable via a user menu and were optimized to reduce triggering to occur only on real Mode S signals with as little false trigger rate as possible. This was critical in order to provide accurate Mode S fruit rate data.

Data analysis has shown that the filters that reduce false triggers for environment analysis also enhance extended squitter reception. A new version of the reception algorithm was

developed to simulate a detection process that could be implemented by emulating the reception limitations of a real-time application. With some of these filters incorporated into the real-time emulation, the recovery time from false triggers can be reduced, therefore maximizing message reception performance.

A real-time emulation is required to determine reception performance that is realistically achievable. The term “RMF Gold Standard” applies to this optimized yet real-time simulated reception technique. The RMF gold standard modifications and real-time simulation method are described below:

### **The 5-5 Multiple Amplitude Method**

Of the 3 methods developed for bit and confidence declaration, the 5-5 multiple amplitude method yields the best performance. Various Frankfurt data samples were processed with all three techniques and evaluated on their ability to detect and decode extended squitters and short squitter messages. The RMF gold standard utilizes the 5-5 multiple amplitude method.

### **Use of DMTL in Preamble Validation**

Data analysis showed that there were occasions where the enhanced decoder would trigger too early on some otherwise valid mode S replies due to the location of fruit prior to a preamble pulse group and prior to the data block. With the combination of low receiver threshold and high fruit rate, it is not that difficult to find a stray pulse position to satisfy the first or second data pulses tested during preamble validation, and then have the actual mode S data block pulses satisfy the rest. Usually the fruit is at a significantly lower amplitude with respect to the actual reply. A solution to this problem is to add an amplitude requirement to the preamble validation step.

The processing order was modified to perform reference level generation prior to preamble validation. This was done so that the dynamic threshold determined by the reference level process can be applied to the preamble validation step. The preamble validation process was modified to not only test for the presence of a pulse at either the 0 or 1 chip of the first five data bit positions, but to also require that the peak amplitude of the pulses found must exceed the dynamic threshold. The dynamic threshold is set to 6 dB below the amplitude of the preamble.

### **Real-time Design Approach**

In order to emulate a reception process that could be applied to a real-time application, a basic design philosophy had to be developed. Figure 1 illustrates the design approach used for the RMF Gold Standard.

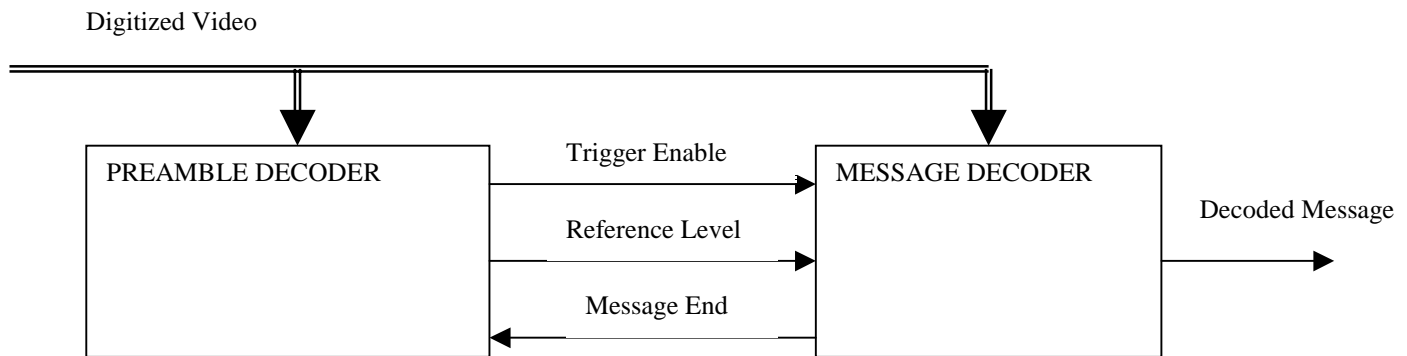


FIGURE 1 – THE RMF GOLD STANDARD DESIGN APPROACH

Since the RMF Gold Standard reception is used to set a standard for extended squitter reception, it is important that the technique applied is able to maximize its capability to trigger on valid messages and to minimize the time required to recover from false triggers. To achieve this, the digitized video is continuously clocked into a preamble decoder and a message decoder in parallel. The preamble decoder contains parallel circuitry that compares delayed versions of the incoming signal in order to trigger when pulses align properly in the 4 preamble pulse positions and the first 5 data bit positions. At the same time the reference level is determined from the 4 preamble pulses. When the preamble decoder triggers, it triggers the message decoder and provides the reference level. Once the preamble decoder triggers, it continues to operate but in a re-trigger mode. When in re-trigger mode the preamble decoder will only trigger again if the new set of pulses exceed the previous trigger by at least 3 dB. After triggering, the preamble decoder will operate in re-trigger mode until the message end signal is received from the message decoder, at which time, it will return to normal trigger mode.

When enabled, the message decoder will continue to decode the message until the end of the message or one of the early termination filters determines that the message is not valid, at which time, the message decoder will signal the preamble decoder to return to normal trigger mode. There are four early termination filters and are described below.

Low Confidence Limit Filter - Message decoding is terminated if more than 12 low confidence bits are declared.

Indeterminate Bit Limit Filter - Message decoding is terminated if 3 consecutive data bits contain a sample pattern of all zero's (all 10 of each bit samples are more than 6 dB below the reference level).

Pulse Position Gap Filter - Message decoding is terminated if within the data block portion of a message there is greater than 30 consecutive samples without a pulse position declared.

DF Code Filter - Message decoding is terminated if it is determined that the message cannot produce a DF code between 16 and 23. This is accomplished by testing the first

two data bit and confidence values. If any or all of these bits that are declared high confidence can not produce a value of 10 (binary) then message decoding is cancelled.

With this design approach, the preamble detector provides continuous triggering capability that is only desensitized by the occurrence of a preamble in combination with preamble validation. With the feedback from the message decoder, the amount of time that the preamble detector is desensitized is minimized when the trigger is determined to be false or a message type that is not wanted.

### **The RMF “Ideal” Standard**

The RMF Gold Standard was developed in such a way as to also provide extended squitter reception data with ideal reception capability without the limitations of the real-time implementation. This is important to gauge the potential reception rate. The ideal reception rate is immune from the problem of messages being lost to false early triggers.

The RMF Gold Standard software processes the digitized video data with a continuous triggering capability that can trigger on any clock cycle from the beginning to the end of the data file completely independent of all previous triggers. When the preamble detector and preamble validation combination triggers, the reference level is used to set a recovery amplitude that will end at a time determined by the message decoder. This recovery amplitude and time are set only if the trigger is either standalone or its amplitude exceeds the current recovery amplitude by at least 3 dB. The message is decoded and stored whether or not it exceeds the current recovery amplitude. To provide the limitations of a real-time application, a status is maintained for each message to indicate if the message is valid with respect to previous triggers, or if the message is precluded by a previous trigger. Subsequently, all decoded messages are stored in an output file with the re-trigger status. The result is a file that contains a complete set of all messages decoded. When analyzing data from the real-time perspective, the re-trigger status is used filter out messages that would not have been detected with a real-time implementation. Data analysis from an ideal message reception perspective would include all messages.